Sedimentary Dynamics of the Rhone, Korean and Other World Deltas and Estuaries

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LONG-TERM GOALS

Coordinate the EuroSTRATAFORM modeling effort. Model the hydrological routing of water and sediment into the Northern Adriatic and the Gulf of Lions. Determine the impact of changes in climate, humans, and sea levels, on the transfer and dispersal of sediment from land to sea. Assess the magnitude and grain size of the sediment load discharged to the global coastal zone. Provide a hydrological assessment of Korean rivers in preparation of the DRI Tidal Flats project.

OBJECTIVES

- Coordinate the EuroSTRATAFORM modeling efforts designed to formulate diagnostic models on how sedimentary processes contribute to the stratigraphic record.
- Determine the long-term and short-term climate changes, and the perturbations from human impacts, on the hydrological routing of water and sediment (e.g., floods, droughts) of the Po, selected rivers along the Apennines, and the Rhone and Tet Rivers.
- Understand how delta lobe switching imparts a recognizable signature on margin architecture (e.g., through plume sedimentation).
- Simulate the dynamic response of a continental margin to large-amplitude sea-level changes, with particular reference to continental shelf sedimentary deposits.

APPROACH

1. Develop a coherent NA-EU community of modelers who together develop and/or employ a suite of numerical tools to simulate events affecting strata formation that are otherwise difficult to observe. Coordinate this modeling activity with scientists collecting field observation, for insight and validation.

2. Combine single-component models into a larger numerical framework, including the conversion of *2D-SedFlux* into *3D-SedFlux*. Compare model results with field data from the Gulf of Lions and the Adriatic.

3. Locate and analyze climate and discharge records for selected rivers in Korea. Using *HydroTrend*, generate synthetic discharge records and sediment loads, across pertinent historical

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and geological periods, and provide results to other DRI participants. Predict flood probability distributions.

WORK COMPLETED

1. Organized and convened EuroSTRATAFORM workshops, coordinating modeling and field efforts, and linking efforts of North American and European projects (EURODELTA, PROMESS, and EU-EuroSTRATAFORM):

a. Helped organize a Joint EuroSTRATAFORM/PROMESS Conference, Salamanca, Spain, Oct. 24-27, 2005; with EU leaders and Nittrouer (UW);

b. Helped organize an ONR EuroSTRATAFORM meeting in Charlottesville, April 24-26, 2006;

c. Coordinated/edited a series of (4) ppt presentations as a final product of meeting participants who summarized project successes for ONR program mangers;

d. Helped organize a final 2006 (fall) AGU EuroSTRATAFORM session “Studies of sediment transfer from land through the ocean and into the stratigraphic record” with conveners: Nittrouer, Kuehl, Syvitski, Durrieu de Madron, & Canals;

e. Helped organize a 2006 AGU session “New Algorithms and models for fluvial and coastal sediment-transport and surface dynamics” with conveners Sherwood, Syvitski, Nelson, & Wiberg;

f. Helped organize a special EuroSTRATAFORM issue of *Geochemistry, Geophysics, Geosystems* (G3) entitled “Interactions between high frequency climate changes and deltaic margin architecture”, to be edited by Berne, Trincardi and Syvitski (submission deadline 05/07)

g. Organized/editor a special issue of Computers & Geosciences entitled PREMISE: Predictive Modeling in Support of EuroSTRATAFORM (submission deadline 09/06).

2. The following papers, described in the 2005 ONR Annual Report, were revised and published or are in the final page-proof stage.

i. Kettner, A.J., Syvitski, J.P.M., in press, Predicting Discharge and Sediment Flux of the Po River, Italy since the Late Glacial Maximum, IAS Special Publication.

ii. Hutton, E.W.H., Syvitski, J.P.M., and Kubo, Y., 2005. Numerical modeling of river deltas. In: Chen, Z., Saito, Y., and Goodbred, S., (Eds.) 2005. Mega-deltas of Asia-Geological Evolution and Human Impact. China Ocean Press, Beijing, pp. 255-261.

iii. Khan S.M., Imran, Bradford, J.S., and Syvitski, J.P.M. 2005, Numerical modeling of hyperpycnal plume. Marine Geology 222-223: 193-211.

iv. Nittrouer, C.A., Austin Jr., J.A., Field, M.E., Kravitz, J.H., Syvitski, J.P.M., and Wiberg, P.L. in press, Writing a Rosetta stone: Insights into continental-margin sedimentary processes and strata. In: Nittrouer, C., Austin, J., Field, M., Steckler, M., Syvitski, J.P.M., Wiberg, P., (Eds.) Continental-Margin Sedimentation: Transport To Sequence. Blackwell Pub.

v. Overeem, I., Syvitski, J.P.M., and Hutton, E.W.H., 2005, Three-dimensional numerical modeling of deltas. In: L. Giosan and J.P. Bhattacharya (Eds.) River Deltas — Concepts, Models, and Examples. SEPM Special Publication No. 83, pp. 13-30.

vi. Parsons, J. Friedrichs, C., Garcia, M., Imran, J., Mohrig, D., Parker, G., Pratson, L., Puig, P., Syvitski, J.P.M., Traykovski, P. in press. Sediment gravity flows: Initiation, transport and deposition. In: Nittrouer, C., Austin, J., Field, M., Steckler, M., Syvitski, J.P.M., Wiberg, P., (Eds.) Continental-Margin Sedimentation: Transport To Sequence. Blackwell Pub.

vii. Pratson, L.F., Hutton, E.W.H. Hutton, A.J. Kettner, and J.P.M. Syvitski, in press, The Impact of floods and storms on the acoustic reflectivity of the inner continental shelf: A modeling assessment. Continental Shelf Research

viii. Syvitski, J.P.M., Kettner, A., in press, On the flux of water and sediment into the Northern Adriatic. Continental Shelf Research.

ix. Syvitski, J.P.M., Kettner, A.J., Correggiari, A., Nelson, B.W. 2005, Distributary channels and their impact on sediment dispersal. Marine Geology 222-223: 75-94.

x. Syvitski, J.P.M., Wiberg, P., Lee, H., Geyer, R., Imran, J., Morehead, M.D., Parker, G., Garcia, M., Steckler, M., Pratson, L., Hutton, E.W.H., in press-b. Prediction of margin stratigraphy. In: Nittrouer, C., Austin, J., Field, M., Steckler, M., Syvitski, J.P.M., Wiberg, P., (Eds.) Continental-Margin Sedimentation: Transport To Sequence. Blackwell Pub.

xi. Trincardi, F., and Syvitski, J.P.M. 2005, Advances on our understanding of delta/prodelta environments: A focus on southern European margins. Marine Geology 222-223: 1-5.

3. Completed ten more papers and submitted for peer-reviewed publication (see Results).

4. Visited Korea twice in 2006 to coordinate tidal flat and hydrological research with Dr. Hee Jun Lee (KORDI), Dr. Kim (KOPRI), Prof. Daekyo Cheong (Kangwon U.). Exchanged information in the effort to characterize the flow regimes of Korean rivers. Studied the massive 2006 Korean floods where ≈ 3000 Koreans perished due to mudslides and drowning.

RESULTS

1. Syvitski, J.P.M., 2005, The morphodynamics of deltas and their distributary channels. In: G. Parker and M. Garcia (Eds.) River, Coastal and Estuarine Morphodynamics, Taylor and Francis Group, London, pp. 143-160.

2. Syvitski, J.P.M., Saito, Y. in review, Morphodynamics of Deltas under the Influence of Humans. Global and Planetary Change.

A consistent database is established to characterize key environmental factors known to control delta morphology (e.g. location, morphology, fluvial and sediment discharge, ocean energy, and bathymetry). Fifty-one deltas cover the global range of rivers entering all major oceans and coastal seas. Seasonal satellite images of the deltas were processed (IKONOS, SPOT, LANDSAT, and MODIS). A delta's area is shown to scale with average discharge, sediment delivery, and offshore accommodation space. The gradient of a delta plain reflects the ratio of sediment supply to sediment retention, suspended sediment concentration used as a proxy of delta plain aggradation, and mean water discharge. The number of distributary channels is predicted by maximum monthly discharge and marine power. Channels form a lognormal distribution in terms of their width, responding to maximum discharge, tidal and wave energy. The grain size of topset deposits scale with river length.

3. Syvitski, J.P.M. and Milliman, J.D., in press, Geology, geography and humans battle for dominance over the delivery of sediment to the coastal ocean. J. Geology.

Sediment flux to the coastal zone is conditioned by geomorphic and tectonic influences (basin area and relief), geography (temperature, runoff), geology (lithology, ice cover), and human activities (reservoir trapping, soil erosion). A new *BQART* model accounts for these varied influences. When applied to a database of 488 rivers, the *BQART* model showed no ensemble over- or under-prediction, had a bias of just 3% across 6 orders of magnitude in observational values, and accounted for 96% of the between-river variation on the long-term (±30y) sediment load or yield of these rivers. The geographical range of the 488 rivers covers 63% of the global land surface and is highly representative of global geology, climate and socio-economic conditions. Geological parameters (basin area, relief, lithology, ice erosion) explain 65% of the between-river sediment load. Climatic factors (precipitation and temperature) account for an additional 14%. Anthropogenic factors account for an additional 16% of the between-river loads, although with ever more dams being constructed or decommissioned, and socio-economic conditions and infrastructure in flux, this contribution is temporally variable.

4. Kubo, Y., Syvitski, J.P.M., Hutton, E.W.H., Kettner, A.J. in press, Inverse modeling of post Last Glacial Maximum transgressive sedimentation using *2D-SedFlux*: Application to the northern Adriatic Sea. Marine Geology

A coupled 21,000 y simulation using the hydrologic model *HydroTrend* and the stratigraphic model *2D-SedFlux* explains the distribution of deposits in the north Adriatic Sea. Discharge of the paleo Po River during late Pleistocene carried a sediment load 70% higher than the load during the Holocene, due to increased glacier melt and enlarged drainage area. Paleo morphology is reconstructed in a pseudo-inverse manner by comparing the *2D-SedFlux* predicted deposit distribution to the modern morphology and accounting for the thick, prograding deposits of the modern Po delta and the Po lowstand delta by drawing back the modern bathymetric profile. The bathymetric profile is next adjusted for aggradational deposits. These sequential simulations produced a likely profile of the morphology buried below the seafloor, which sees accommodation matching sediment supply.

5. Hutton E.W.H., and Syvitski, J.P.M.: in review. *SedFlux* 2D and 3D: New advances in the seafloor evolution and stratigraphic modular modeling system. Computers and Geoscience.

This paper documents the latest *SedFlux* code, and describes new or revised: 1) nearshore longshore transport module; 2) bottom boundary layer module for cross shelf current-wave interaction, 3) momentum-balanced turbidity current and hyperpycnal flow modules, 4) 2D isostatic subsidence and flexural response module, 5) multiple rivers inputs, 6) generation and avulsion of distributary channels of a delta, 7) erosion and deposition within the river channel, 8) coastal hugging and Kelvin wave influenced hypopycnal plumes, 9) anisotropic diffusion module for shelf sediment flux, and 10) upgraded modules for geotechnical and acoustic properties. The nearshore-to-shelf sediment-transport module modifies the seafloor through a surface-gravity wave field and bottom currents, and their interaction with a multi-grain-sized sea-bottom. The waves are transmitted towards the shore and their shape modified using the dispersion relation for surface gravity waves (deep water to shallow water waves). An advection-diffusion (offshore) approach allows for grain-size dependency on sediment transport as a function of near-bed orbital velocities. The model allows for a clinoform developing in an offshore direction, with or without the input of fluvial material. Applied to the EuroSTRATAFORM sites, the model develops offshore clinoforms of the same architecture (bedding, geometry, grain size, water depth) as determined from seabed mapping. A scaling routine allows an event-based to produce results similar to the more numerically taxing daily-time step approach.

6. Kettner A.J., Syvitski, J.P.M., in review, *HydroTrend* v3.0: a Climate-Driven Hydrological Transport Model that Simulates Discharge and Sediment Load leaving a River System. Computers & Geosciences

HydroTrend v.3.0 is a climate-driven hydrological water balance and transport model that simulates the water discharge and sediment load at a river outlet, by incorporating drainage basin properties (river networks, hypsometry, relief, reservoirs) together with biophysical parameters (temperature, precipitation, evapo-transpiration, and glacier characteristics). *HydroTrend* generates daily discharge values through: snow accumulation and melt, glacier growth and ablation, surface runoff, and groundwater evaporation, retention and recharge. The long-term sediment load is predicted either by the *BQART* module that incorporates drainage area, discharge, relief, and temperature, basin-averaged lithology and anthropogenic influences on soil erosion. Sediment trapping efficiency of reservoirs is based on reservoir location in the river network and the residence time of water within the reservoir. Glacial influence is based on the extent of ice cover, equilibrium altitude, and freezing line mobility. *HydroTrend* v.3.0 captures the inter- and intra-annual variability of sediment flux by using either high-resolution climate observations or a stochastic climate generator for simulations over longer geological intervals. A distributary channel module simulates the flow conditions and transport capacity across a multiple deltaic channel system. Simulations of the Metauro and the Po Rivers, Italy, are used as case studies and show the model captures flood events and their sediment load.

7. Jouet, G, Hutton, E.W.H., Syvitski, J.P.M., Rabineau, M., Berné, S. in review, Modeling the isostatic effects of sea level fluctuations on the Gulf of Lions. Computers & Geosciences

8. Mixon, D.M., Kinner, D.A., Stallard, R.F., and Syvitski, J.P.M. in review, Geolocation of man-made reservoirs across terrains of varying complexity using GIS. Computers & Geosciences

The Reservoir Sedimentation Survey Information System (RESIS) is one of the world's most comprehensive databases of reservoir sedimentation rates, comprising nearly 6,000 surveys for 1,819 reservoirs across the continental United States. The use of this database for large-scale studies has been limited by the lack of precise coordinates for the reservoirs. Many of the reservoirs postdate current topographic maps and have only township and range coordinates. A method scripted in ESRI's ARC Macro Language (AML) locates reservoirs on, for example, 30 m digital elevation models using information available in RESIS. The script delineates the contributing watersheds and compiles several hydrologically important parameters for each reservoir. For watersheds > 5 km2, the correct outlet is identified over 80% of the time.

Misidentifying a watershed outlet does not necessarily mean that the watershed characteristics are misrepresented.

IMPACT/APPLICATIONS

A series of high-quality and consistent databases have been acquired to characterize the world's coastal zone, with an emphasis on rivers and deltas. These databases analyzed for patterns yield predictive equations. For example, the *BQART* model makes possible the quantification of the influencing factors (e.g., climate, basin area, ice cover) within individual basins, to interpret better the terrestrial signal in marine sedimentary records. The *BQART* model predicts the long-term flux of sediment delivered by rivers. When coupled to hydrological models and marine sediment transport models (*HydroTrend, SedFlux*), *BQART* better supports predicting the episodicity (e.g., typhoons, earthquakes) of sediment delivery to continental margins. The sequence of models is widely penetrating the academic community.

Hundreds of millions of people occupy deltas and human engineering now controls the growth and evolution of many deltas, through control of the flow path of distributary channels, and mitigation of the seasonal flood wave with concomitant change in the delivery of sediment load. More and more deltas are moving away from their historical equilibrium between sediment supply and sediment dispersal.

Sequential simulation offers an effective method to recover subsurface morphology, information that is critical in characterizing the seafloor acoustic properties, including sub-surface wave-guides and sonar geoclutter.

TRANSITIONS

ExxonMobil is using versions of *HydroTrend* and *SedFlux2D* and *3D* in their industrial applications. The International Geosphere Biosphere Program use the models to examine the global water system through its core projects (GWSP and LOICZ).

RELATED PROJECTS

ONR Geoclutter: Predicting the Distribution and Properties of Buried Submarine Topography on Continental Shelves. (http://instaar.colorado.edu/deltaforce/projects/geo_clutter.html)

ONR Seabed Uncertainty: Seabed Variability and its Influence on Acoustic Prediction Uncertainty. (http://instaar.colorado.edu/deltaforce/projects/dri.html)

PUBLICATIONS

Kettner, A.J., Syvitski, J.P.M., in press, Predicting Discharge and Sediment Flux of the Po River, Italy since the Late Glacial Maximum, IAS Special Publication. [in press, refereed]

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